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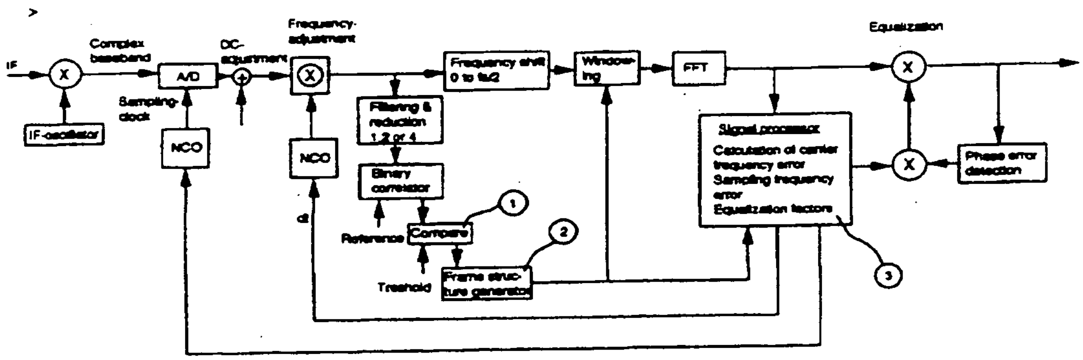
(54) Title: METHOD AT OFDM-RECEPTION FOR CORRECTION OF FREQUENCY, TIME WINDOW, SAMPLING CLOCK AND SLOW PHASE VARIATIONS



(57) Abstract

The present invention relates to a method for correction of frequency, time window error, sampling clock and phase error at OFDM-receivers. The information which is transmitted in a signal which includes several carriers in digital form, includes consecutive frames comprising a number of symbols. In respective frames at least one up-chirp and one down-chirp is arranged. Correction of the frequency is made based on analysis of the up- and down-chirps. Further the main focus of the weighted impulse response is determined. The position of the main focus is used for correction of the time window and the sampling clock. Further the vectors from the location of the received carriers are registred in relation to their ideal location in a matrix. The angles between the received vector and the ideally located vector are determined and are weighed together with regard to the amplitude of the transmission function at the frequency of the carrier and the distance of the vector to the origin of coordinates. An average is after that made of the weighed angle distances. The obtained average is used for correction of the phase error. Further, the knowledge of the obtained phase error and previous phase errors is used for estimation of the coming phase error in the following reception.

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TITLE OF THE INVENTION

Method at OFDM-reception for correction of frequency, time window, sampling clock and slow phase variations.

TECHNICAL FIELD

The present invention relates to a method at digital system for correction of frequency, sampling clock and phase error which varies slowly with time, i.e. low-frequency phase noise. The receiver is a so called OFDM-receiver which receives digital information in frames.

PRIOR ART

OFDM (Orthogonal Frequency Division Multiplex) is a type of modulation where a digital signal is multiplexed on many narrow-band carriers. The narrow-band carriers are packed with high density because one utilizes the fact that the carriers are orthogonal when the carrier separation is equal to 1 divided by the symbol lenght for rectangular symbols. The implementation of OFDM is usually made by means of special circuits which perform FFT (Fast Fourier Transform). At OFDM-signalling, channel coding and so called soft decoding (for instance Viterbi-decoding) is usually used in order to reduce the probability of error and make it possible to deal with frequency selective fading. OFDM combined with the mentioned channel coding is called COFDM (Coded Orthogonal Frequency Division Multiplex). System using this form of signalling have of recent years been implemented for different types of broadcasting, i.e. one-way systems for digital broadcasting and for digital TV.

The Patent document EP 448 493 describes a system for transmission of TV digitally. The picture information is transmitted to a mobile user and is divided into two parts; one is used to recreate a normal TV-picture and the other together with the first one to create a larger picture. In the document EP 441 732 is described a receiver for digital radio signals. The receiver utilizes a window method to minimize the intersymbol interference arising at multipath propagation. In order to reduce the negative effects at the loss of the orthogonality of the carriers at the reception, the receiver will be equipped with a time window module which is used to extract usable samples from the received signal.

The American document US 5 228 025 describes a method to transmit digital data via radio, preferably to mobile receivers. The method transmits a synchronization sequence in the form of at least one frequency which varies in one for the receiver known way. At the receiver the synchronization sequence is utilized for tuning the local oscillator.

In the first prototype for transmission and reception of DAB (Digital Audio Broadcasting) two sync symbols are used. The first is called zero symbol and contains nothing but is used by the receiver on one hand for symbol synchronization, and on the other for estimation of interference in the channel. The second symbol consists of a so called chirp or sine sweep signal which is a sine shaped signal, the frequency of which changes linearly with time and which sweeeps over the whole channel width. This is used by the receiver on one hand for adjustment of the location of the time window, i.e. division of the received signal in segments which are each processed by means of FFT, and on the other for

estimation of the transmission function of the channel and estimation of deviations in the carrier frequency, if any. In the final DAB-specification the chirp symbol has been replaced by a so called TFPC-signal (Time Frequency Phase Control), also called CAZAC-symbol, which is used by the receiver both for timing, frequency adjustment and for estimation of the transmission function.

DESCRIPTION OF THE INVENTION/TECHNICAL PROBLEM

Transmission of information by means of OFDM-technology makes quite different demands upon accuracy than in conventional systems. The normal synchronization which takes place between transmitter and receiver in conventional broadcasting systems is at transmission of program information in digital form with COFDM not sufficient. There is, accordingly, a need for accurate estimation of frequency, time window, sampling clock and compensation of phase noise.

THE SOLUTION

The present invention relates to a method for correction of frequency, time window, sampling clock and time variable phase error at OFDM-reception. One from a transmitter transmitted signal is received by the OFDM-receiver. The signal, which is divided into consecutive frames, which each in its turn is divided into symbols, contains with certains intervals reference symbols with a predetermined content. Each frame is divided into a number of symbols which regarding time follow each other. Respective symbol is allotted a serial number, and the mentioned reference symbols are preferably

transmitted in pairs. The receiver analyzes the different reference symbols. The signals in the reference symbols consist of so called chirp signals, i.e. so called sine sweeep signals which are sine signals the frequency of which is linearly changed with the time and which sweeps over the whole channel width. One of the chirp signals goes from the highest frequency to the lowest in time, and the other chirp signal from the lowest frequency to the highest frequency. The relation between the contents of the reference symbols in pair regarding time and frequency is utilized for adjustment of the frequency of the receiver. Further, the impulse response is calculated from the signals of the received reference frames at which correction of time window and sampling clock can be performed. The main focus of the impulse response is determined, at which the real position of the time window can be determined. By means of the obtained result the position of the time window is adjusted in relation to wished position by the sampling clock being adjusted in relation to the difference between the mentioned main focus and wished position. Each symbol consists of a number of superimposed carriers with among themselves different frequencies. For each of the carriers further is arranged that its phase and amplitude, which can also be described by its real and imaginary part, is modulated by the data information which shall be transmitted. The mentioned real and imaginary parts are allotted a definite position in a matrix system. In the matrix system real and imaginary parts are allowed to take different positions which are accepted. The relation between the point which is indicated by received real and imaginary part and the ideal position in the matrix indicates an angle difference to the ideal position which is utilized for correction of the phase error at reception.

ADVANTAGES

The indicated method gives a possibility to make accurate adjustments of the receiver in a way which has not previously been possible and which gives increased robustness at OFDM-reception. The method further allows that the necessary adjustments in the receiver are possible to perform in a simple way. The method thus allows that the program transmission can be performed with the high precision which is expected in these connections.

DESCRIPTION OF FIGURES

Figure 1 shows schematically how the receiver at first locates the chirp signals by means of a set of binary correlators and after that precision adjusts time window, carrier frequency and phase according to the invention.

Figure 2 shows how the OFDM-signal is created by means of IFFT (Invers Fast Fourier Transform). Each entry on the IFFT corresponds to a carrier.

Figure 3 shows the matrix for estimation of phase error with points according to the 16QAM-system and illustrates the angle relation between the real position of the received vector and the ideal position.

DETAILED EMBODIMENT

A signal sequence is transmitted from a transmitter and received by a receiver. The signal sequence comprises a number of symbols which are arranged to a frame. At the

beginning of each frame one or more synchronization symbols are arranged. At least two of the mentioned synchronization frames contain so called chirp signals. A chirp signal is a sine signal the frequency of which is changed linearly with time. In order to detect the position of the chirp signal a set of correlators are used. The auto correlation for a chirp signal has a very acute maximum. In the receiver the symbol bit of the chirp signal is received and is compared with a stored signal. The signal is compared by being processed through a number of XNOR-gates. The number of equal bits, i.e. the hamming weight of the resulting vector is obtained as an output signal from the correlator. The synchronization signals which at that are obtained in 1 in Figure 1 are brought back to a frame structure generator, 2 in Figure 1, which controls division of the incoming signal in frames and symbols, and numbers the individual samples within each symbol. The frame structure generator in this way controls the division of the signal in appropriate time windows to the FFT (Fast Fourier Transform). The symbols coming out from the FFT are after that forwarded to among other things a signal processor, 3 in Figure 1, where correction values for carrier frequency and the frequency of the sampling clocks is calculated. The transmitted signal from the transmitter has been created by means of an IFFT (Inverse Fast Fourier Transform) according to Figure 2. For an up-chirp signal each of the carriers has been given an amplitude and phase according to he formula $e^{j\pi\kappa^2}/N$, where k corresponds to the number of the carrier, and N the number of carriers. A down-chirp signal is created in a similar way but with negative phase; consequently the formula becomes $e^{-j\pi\kappa^2}/N$. The received signal is made subject to a Fast Fourier Transform (FFT) in the receiver. The correction

calculations which are performed in unit 3 in Figure 1 implies that a multiplication by the for the carrier allotted inverse angle is performed by received up-chirp being multiplied by an ideal down-chirp, and that received down-chirp is multiplied with an ideal up-chirp. The in this way obtained signals, which we call de-rotated chirps, each constitutes an estimate of the transmission function of the channel. For an ideal channel these estimates become equal to 1 for all carriers. If a shift of the carrier frequency has occurred somewhere in the channel, the de-rotated chirps will have a remaining phase shift which is linearly depending on the serial number of the carrier. The changes get different symbols in the up- and the down-chirp. The phase positions of the de-rotated chirps are also influenced by frequency selective fading and by wrong setting of the time window, but this influence has the same symbol in both chirps. Therefore the carrier error can be extracted by subtraction of the de-rotated phase positions of one of the chirps from the other. Then the influence of the carrier error is doubled, whereas other influence is eliminated. The numerical value of the carrier error can in one in itself known way be estimated from the phase position´s linear depending on the carrier number. The obtained number is after that utilized in an in itself known way to correct the frequency.

The impulse response of the channel is obtained by an IFFT-transform on the de-rotated chirps. In order to reduce the influence of the noise on the main focus calculation the impulse response is multiplied with a weighting function before the position of the main focus is calculated. The difference between this position and a predetermined wished position constitutes a correction signal which after filtering controls the

clock-frequency of the A/D-converter, at which the correction value successively will be adjusted towards zero. Consequently the time window will land up in wished position.

The impulse response of the channel can be estimated both from received up-chirp and down-chirp. It is to advantage to use the sum of these two estimates at the main focus calculation because an error in carrier frequency will influence the position of the main focus with different symbols depending on whether it is calculated on an up-chirp or on a down-chirp. The main focus position of the sum of the two impulse responses will therefore be insensible to errors in carrier frequency because the error will neutralize itself.

The received carriers are arranged in a matrix system with respect to their imaginary respective real part. These points are in the complex number plan allotted an area within which they are allowed to exist. A point in the complex number plan which occur within the mentioned area is regarded to symbolize a certain transmitted data sequence. The relation of the point to the ideal position indicates an angle relation between the ideal position and the real position. The mentioned angle difference indicates the phase error in the reception. The average of the angle differences calculated from all the different carriers in the same symbol constitutes an estimate of the phase error. The in this way obtained phase error can after that be combined with previously obtained phase errors and be utilized for phase correction of all carriers in the symbol in question, and for estimation of the expected phase error at the reception of next symbol. It can also be used for estimation of small frequency deviations because these

give rise to phase errors with constant change from symbol to symbol.

The mentioned method for estimation of the phase error can be further developed in different ways. Two different improvements of the method have been identified. One or both improvements can be applied.

The first improvement is based on the fact that the amplitude of the received signal on one and the same occasion can be of different strength for different carriers, frequencies. This is due to interference from reflections of the signal, so called multipath propagation, or interference from other transmitters which transmits the same signal in a so called single frequency network. The carriers which are subject to destructive interference are weakened and get a worse signal/noise-relation than the other. The frequency depending transmission function for the channel can be calculated in the receiver by analysis of the received chirps. At calculation of the average of the angle differences the values from the different carriers can be weighted with the calculated transmission function at which angle differences from carriers with high attenuation in the channel is given a lower weight than those with low attentuation. The strong noise from the attenuated carriers can by that be made to have a minimal influence on the estimation of the phase error.

The second improvement is based on the fact that one and the same noise effect in the received signal gives different uncertainty in the estimation of the phase error for signals far from or close to the origin of coordinates. In order to bridge this state of things the mentioned angle relations are weighed in relation to the distance to the origin of coordinates.

The invention is not restricred to the above as example shown embodiment but may be subject to modifications within the frame for the following patent claims and idea of invention.

PATENT CLAIMS

1. Method at OFDM-demodulation for correction of carrier frequency, phase error, time window and frequency of sampling clock, at which one at the OFDM-receiver received signal is divided into symbols and at defined intervals is allotted symbols and on defined intervals are allotted reference symbols with a predetermined content, and the signal comprises a number of carriers where each carrier is allotted a serial number and the reference symbols can be transmitted in pairs, c h a r a c t e r i z e d in that the received reference symbols are analysed in the receiver, that the contents of the received reference symbols with respect to time and frequency indicate how the carrier frequency in the receiver shall be adjusted, that the impulse response of the channel is calculated from the signals of the reference symbols at which correction of the time window and the frequency of the sampling clock is performed, that the position of the complex vectors of the received demodulated carriers is compared with an ideal position at which deviation from the mentioned ideal position is utilized for correction of the phase error at the reception.

2. Method according to patent claim 1, c h a r a c t e r i z e d in that the position of the complex vectors of the received demodulated carriers are arranged in a matrix system with respect to their imaginary respective real part, that each vector is allotted an area within which it is indicated to exist, and that a vector occurring within mentioned area is at a certain angle distance from the ideal position, and that the mentioned angle distance is utilized for calculation of the phase error.

3. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the amplitude of the received signal is different in strength for different carriers depending on whether the receiver receives more signals, that the phase error estimation for respective carrier is weighted depending on the amplitude of the transmitting function at current frequency, at which a signal with higher amplitude is given a higher weighting than a signal with lower amplitude.

4. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the vectors depending on their amplitude, i.e. their distances from the origin of coordinates, are given different weights, which weights compensate for the amplitude depending influence of the noise on the angle error, at which the angle distance farthest away from the origin of coordinates is allotted a higher weighting than those which are close to the origin of coordinates, and that a correction of the phase error is performed corresponding to the weighted angle error.

5. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the latest obtained phase error is compared with previously obtained phase error and that the expected phase error at reception of next sequence is calculated.

6. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the position of the main focus of the impulse response of the channel is determined, which position indicates the real position of the time window, and that the position of the time window is adjusted in relation to the difference between real position and wanted position by

the frequency of the sampling clock being adjusted in relation to the mentioned difference.

7. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that amplitude and phase of the carriers in the reference symbols are related to the frequency of respective carrier.

8. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the contents of the reference symbols consist of chirp signals.

9. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the reference symbols are transmitted in pairs at which the reference symbols in pairs are allotted one a up-chirp and the other a down-chirp.

10. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that amplitude and phase of the carriers in the up-chirps is defined by $e^{j\pi\kappa^2/N}$ and in the down-chirps by $e^{-j\pi\kappa^2/N}$, where N represents the number of carriers, k the serial number of respective carrier, and $j^2 = -1$.

AMENDED CLAIMS

[received by the International Bureau on 19 April 1996 (19.04.96); original claims 1-10 replaced by amended claims 1-7 (2 pages)]

1. Method at OFDM-demodulation for correcting of carrier frequency, phase error, time window and frequency of sampling clock, at which one at the OFDM-receiver received signal is divided into symbols and at defined intervals is allotted symbols and on defined intervals are allotted reference symbols with a predetermined content, and the signal comprised a number of carriers where each carrier is allotted a serial number and the reference symbols can be transmitted in pairs, the received reference symbols are analysed in the receiver, and the contents of the received reference symbols with respect to time and frequency indicate how the carrier frequency in the receiver shall be adjusted, the impulse response of the channel is calculated from the signals of the reference symbols at which correction of the time window and the frequency of the sampling clock is performed, the position of the complex vectors of the received demodulated carriers is compared with an ideal position at which deviation from the mentioned ideal position is utilized for correction of the phase error at the reception, c h a r a c t e r i z e d in that amplitude and phase of the carriers in the reference symbols are related to the frequency of respective carrier.

2. Method according to patent claim 1, c h a r a c t e r i z e d in that the position of the complex vectors of the received demodulated carriers are arranged in a matrix system with respect to their imaginary respective real part, that each vector is allotted an area within which it is indicated to exist, and that a vector occurring within mentioned area is at a certain angle distance from the ideal position, and that the mentioned angle distance is utilized for calculation of the phase error.

3. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the amplitude of the received signal is different in strength for different carriers depending on whether the receiver

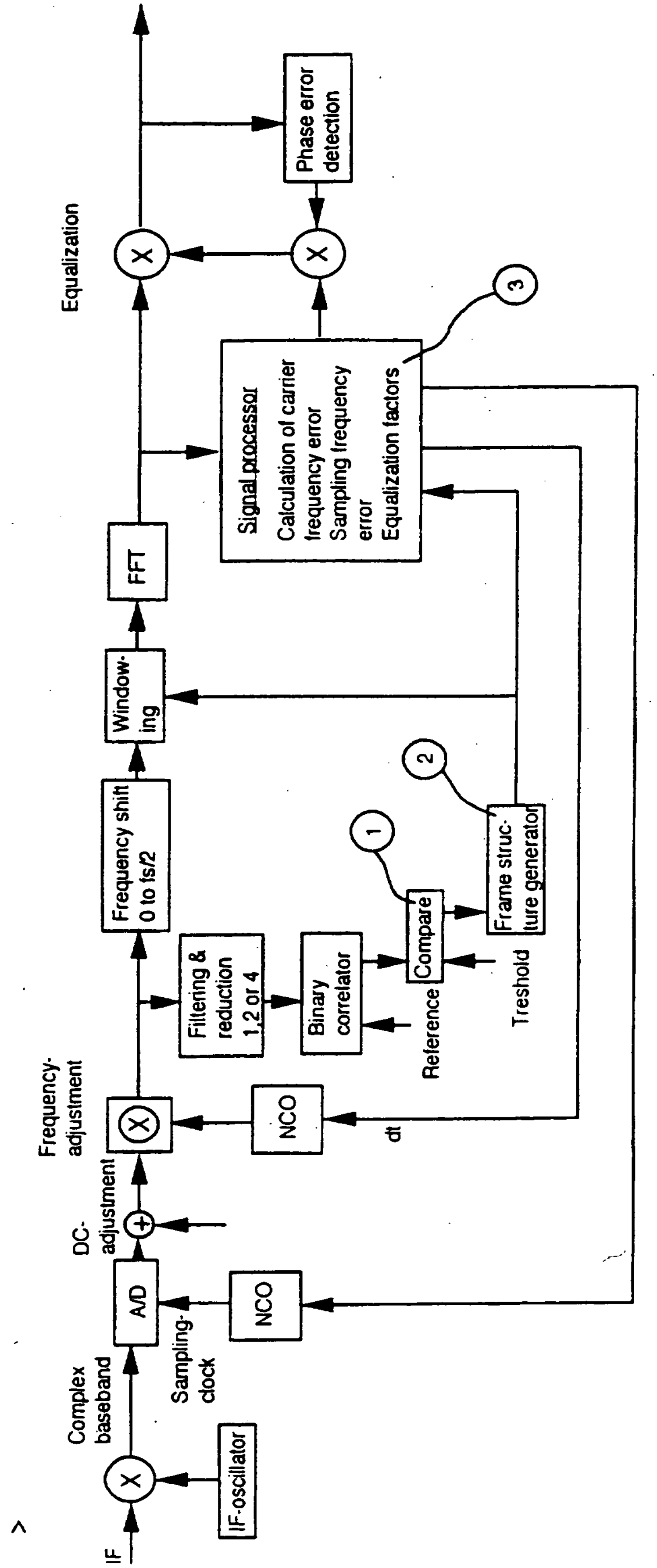
receives more signals, that the phase error estimation for respective carrier is weighted depending on the amplitude of the transmitting function at current frequency, at which a signal with higher amplitude is given a higher weighting than a signal with lower amplitude.

4. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the vectors depending on their amplitude, i.e. their distances from the origin of coordinates, are given different weights, which weights compensate for the amplitude depending influence of the noise on the angle error, at which the angle distance farthest away from the origin of coordinates is allotted a higher weighting than those which are close to the origin of coordinates, and that a correction of the phase error is performed corresponding to the weithted angle error.

5. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the latest obtained phase error is compared with previously obtained phase error and that the expected phase error at reception of next sequence is calculated.

6. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the position of the main focus of the impulse response of the channel is determined, which position indicates the real position of the time window, and that the position of the time window is adjusted in relation to the difference between real position and wanted position by the frequency of the sampling clock being adjusted in relation to the mentioned difference.

7. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the contents of the reference symbols consist of chirp signals.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Compare
Treshold
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Frame struc-ture generator
2
Frequency shift 0 to fs/2
Window-ing
FFT
Signal processor
Calculation of carrier frequency error
Sampling frequency error
Equalization factors
3
Equalization
Phase error detection

Figure 1

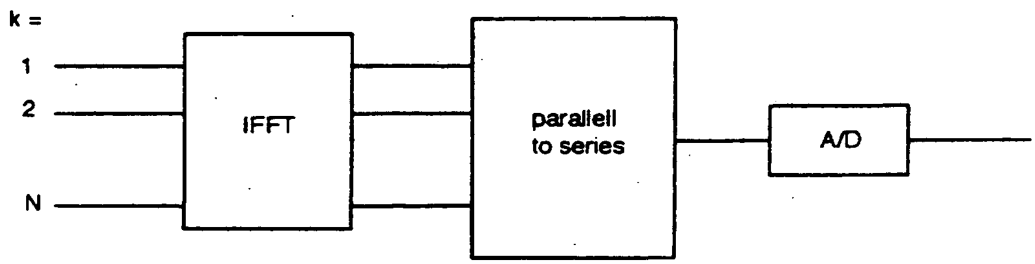

Figure 2

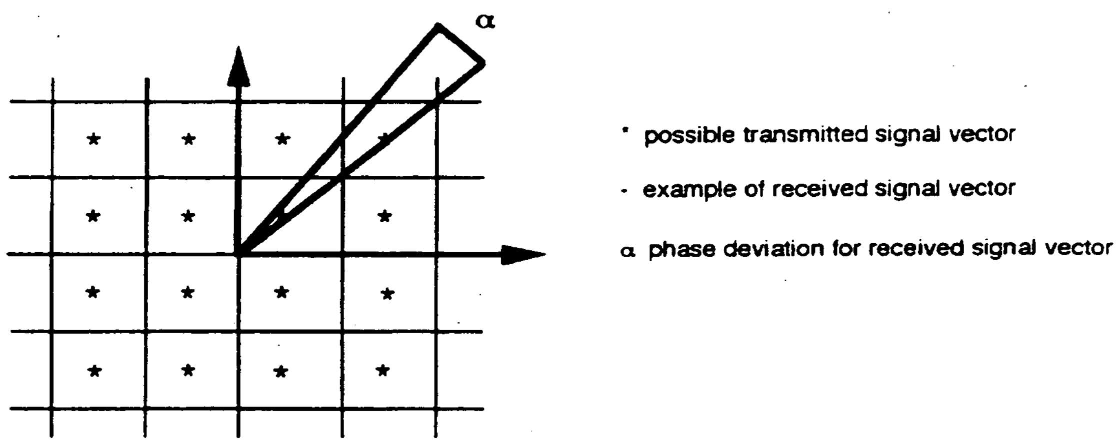

Figure 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 95/01413

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04L 5/06
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B. FIELDS SEARCHED

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0529421 A2 (DAIMLER-BENZ AKTIENGESELLSCHAFT), 3 March 1993 (03.03.93), page 3, line 15 - line 41; page 6, line 1 - line 8; page 8, line 6 - line 21, abstract	1,8
Y		2,3,5
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Y	US 5345440 A (J. GLEDHILL ET AL), 6 Sept 1994 (06.09.94), column 8, line 1 - column 9, line 55, figure 5	2
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Y	EP 0618697 A2 (GRUNDIG E.M.V.), 5 October 1994 (05.10.94), page 5, column 52 - column 58	3,5
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INTERNATIONAL SEARCH REPORT

Information on patent family members

05/02/96

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